Review of Adsorption Technology for the Removal of Emerging Contaminants

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Activated Carbon Adsorption

- Is a process whereby molecules are transferred from a fluid stream and concentrated on a solid surface by chemical reactions with the surface or by physical forces (i.e., Van der Waals forces).

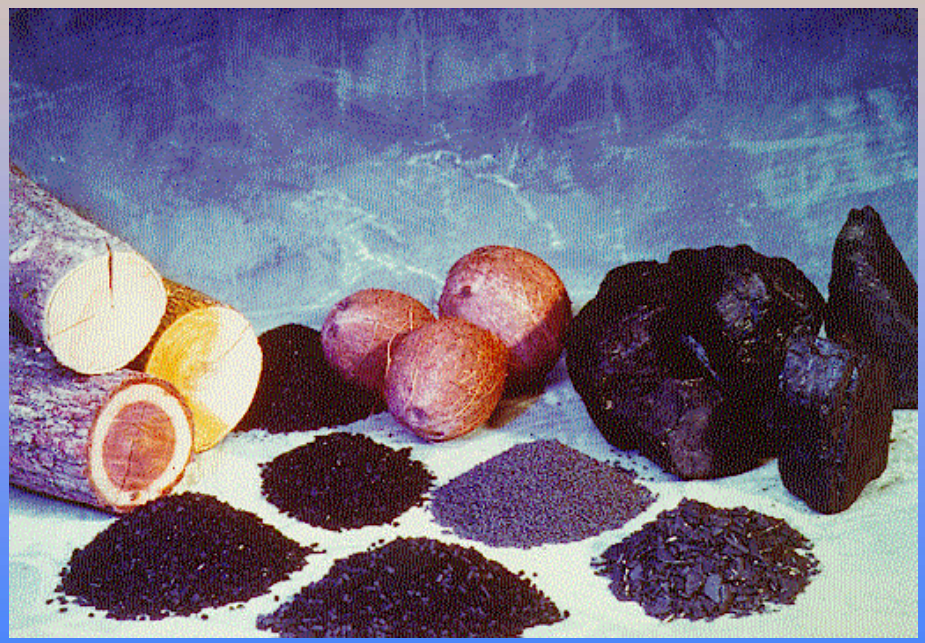
Activated Carbon

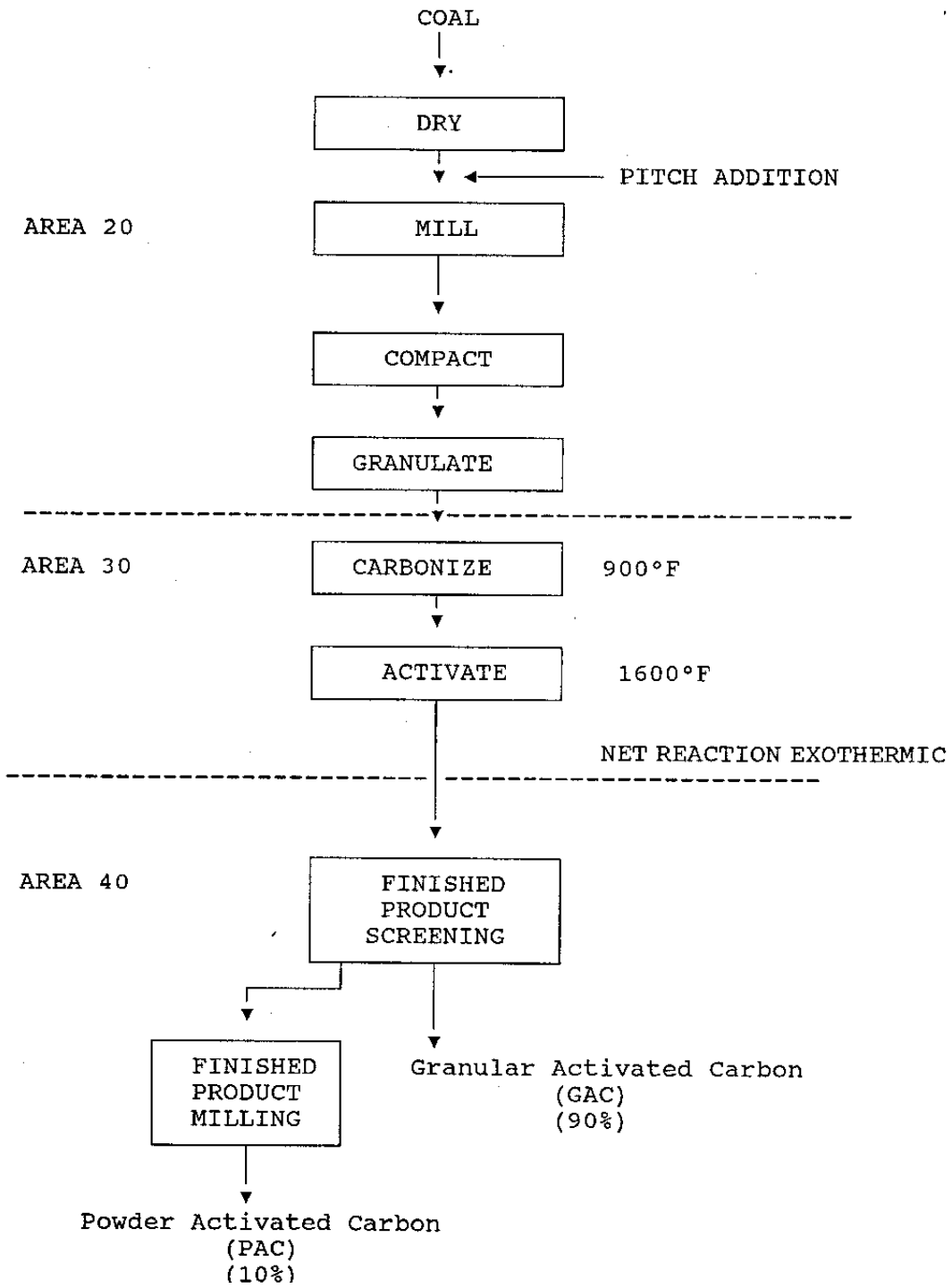
- A carbonaceous material manufactured by 2 steps.
- First step, which is called carbonization, is heating a high carbon content material and driving off water, tars, etc. and creating graphite. (500 to 900 F)
- The second step, which is called activation, is the development of pores using carbon dioxide or steam at a high temperature. (1600 F)

Base Material

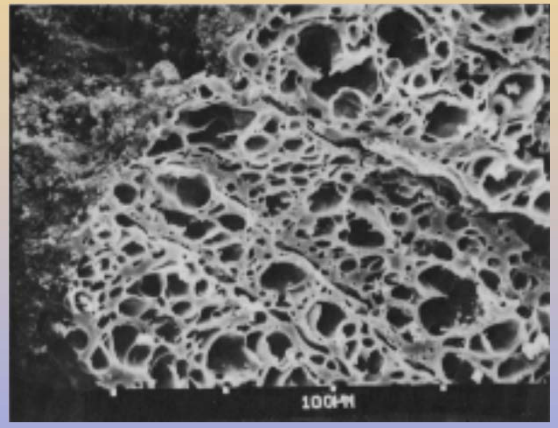
(Barneby & Sutcliffe Corp.)

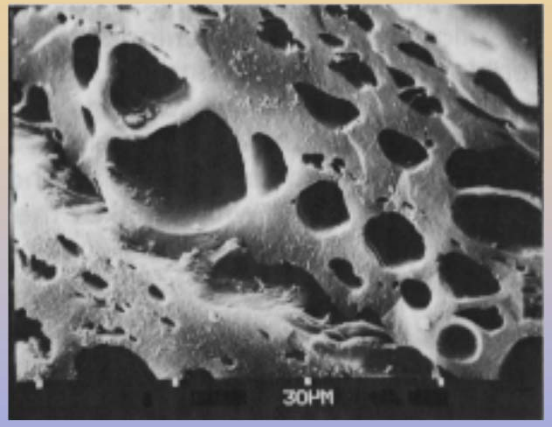
- Coconut Shell
- Bituminous Coal
- Lignite
- Peat
- Wood
- Petroleum
- Bone Char

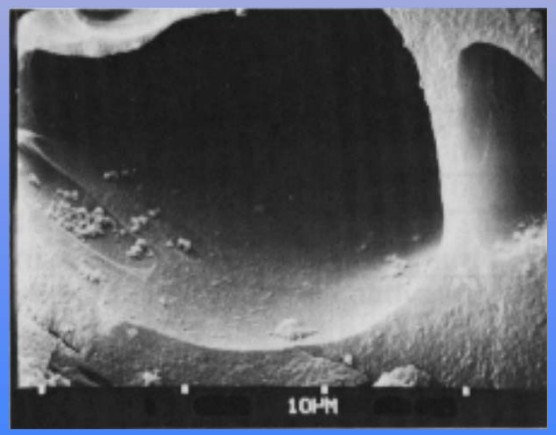


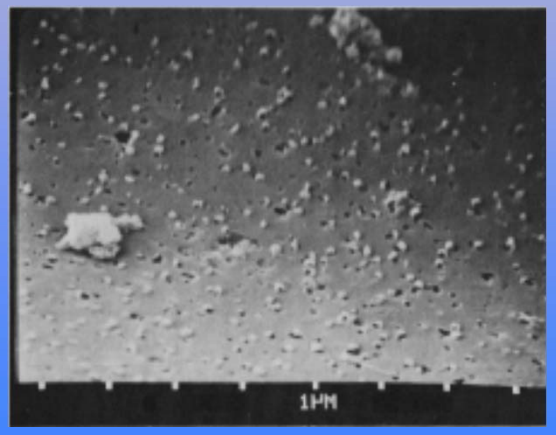

COAL
DRY
PITCH ADDITION
AREA 20
MILL
COMPACT
GRANULATE
AREA 30
CARBONIZE
900°F
ACTIVATE
1600°F
NET REACTION EXOTHERMIC
AREA 40
FINISHED PRODUCT SCREENING
FINISHED PRODUCT MILLING
Granular Activated Carbon (GAC) (90%)
Powder Activated Carbon (PAC) (10%)

Activated Carbon Micrographs

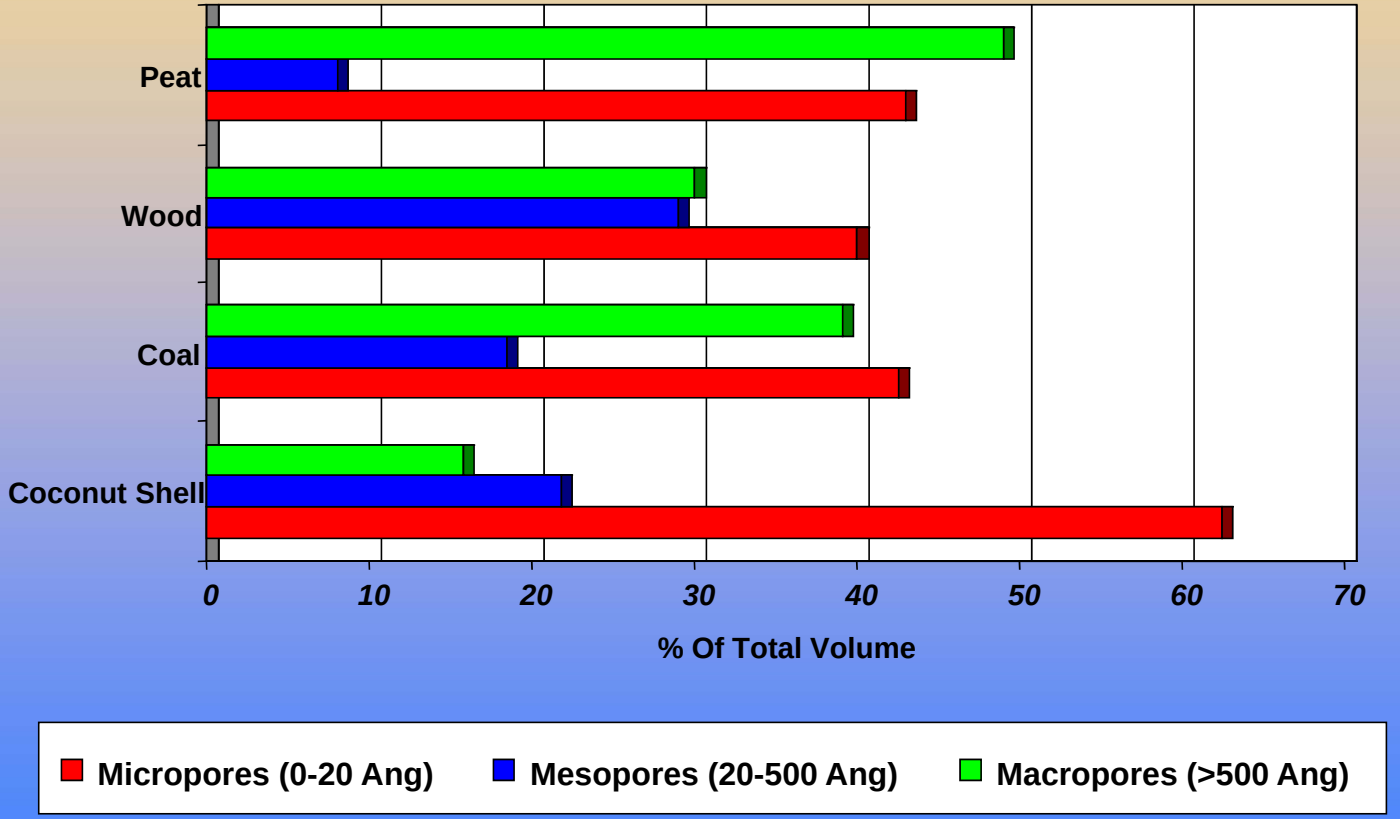




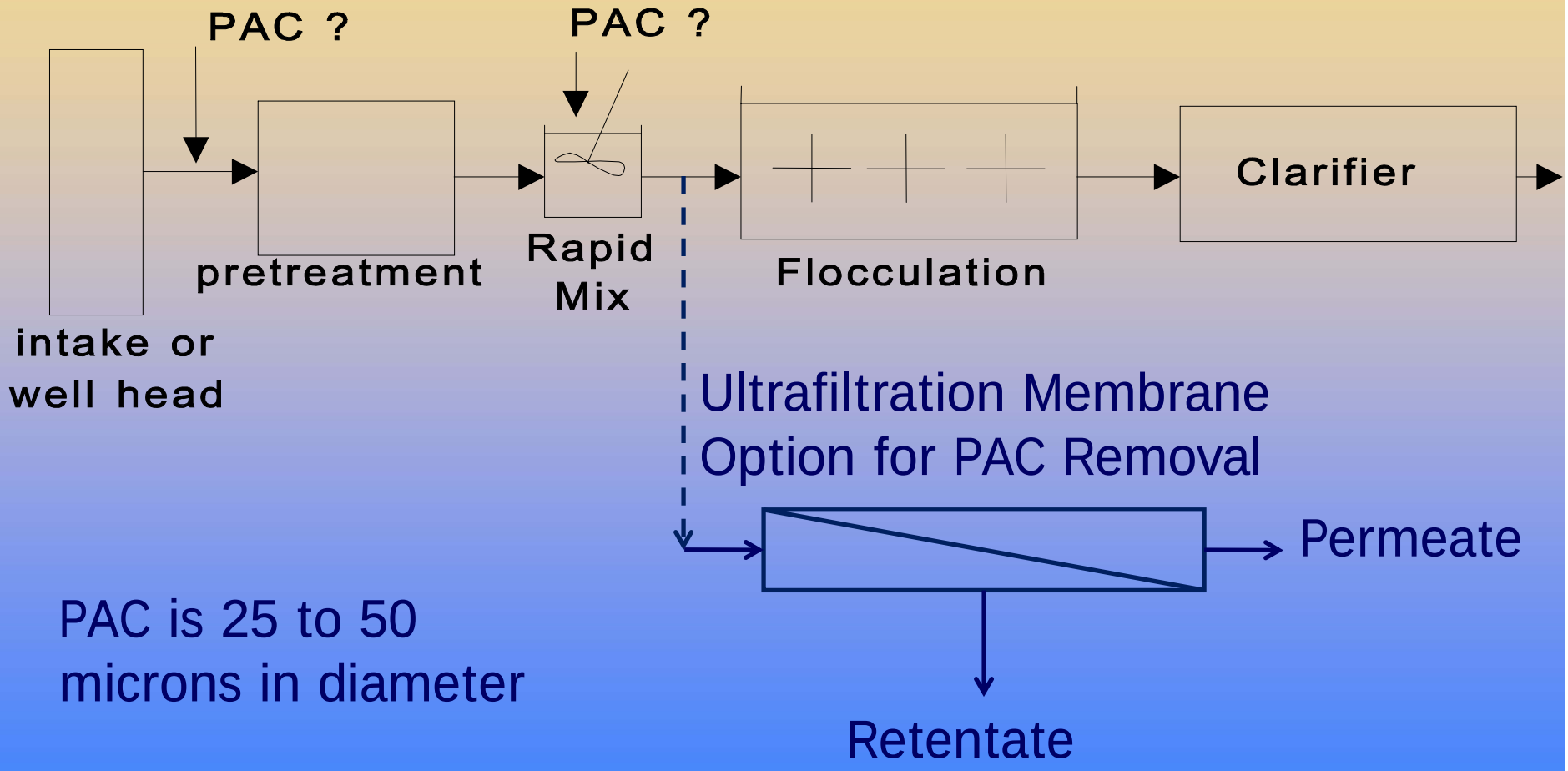




Pore Size Distribution Analysis
(Barneby & Sutcliffe Corp.)



Powdered Activated Carbon (PAC)



PAC is 25 to 50
microns in diameter

GAC Concrete Gravity Feed Filter

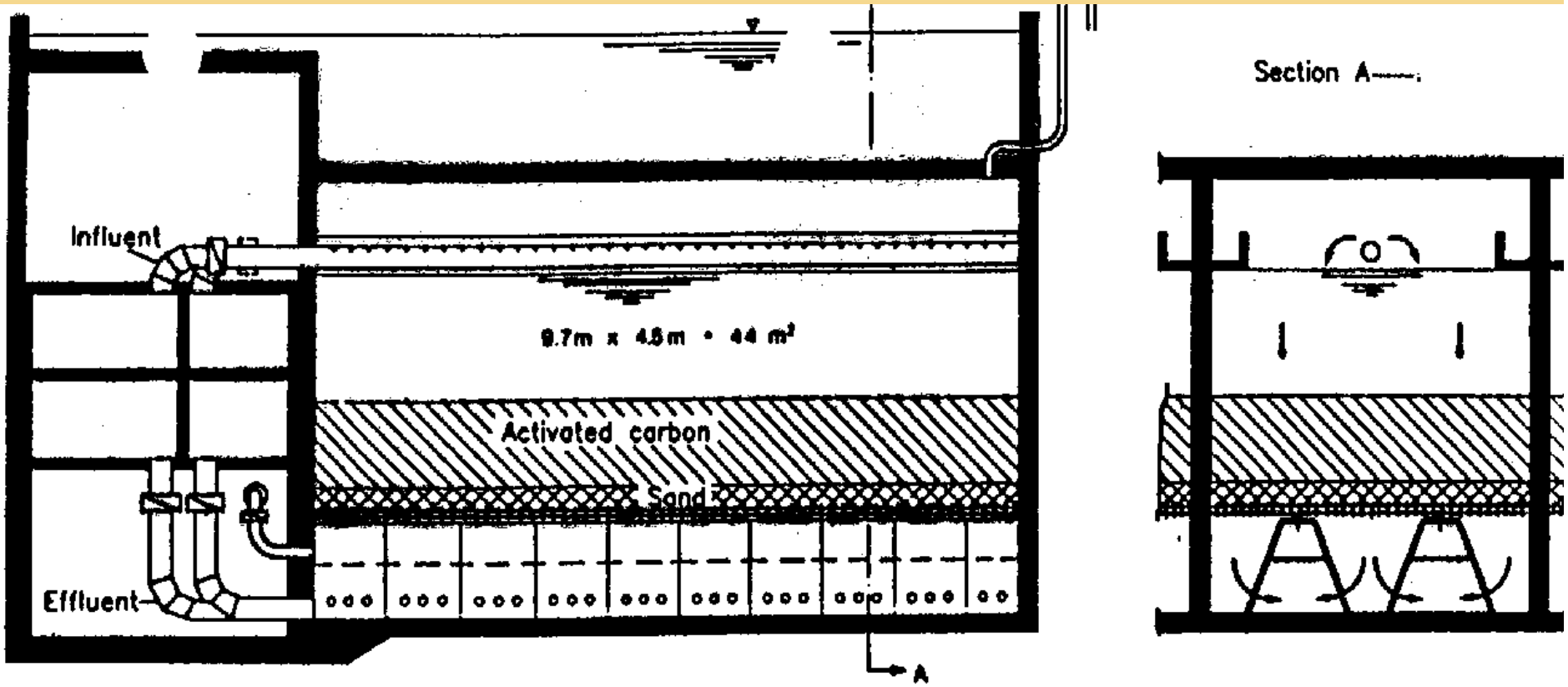
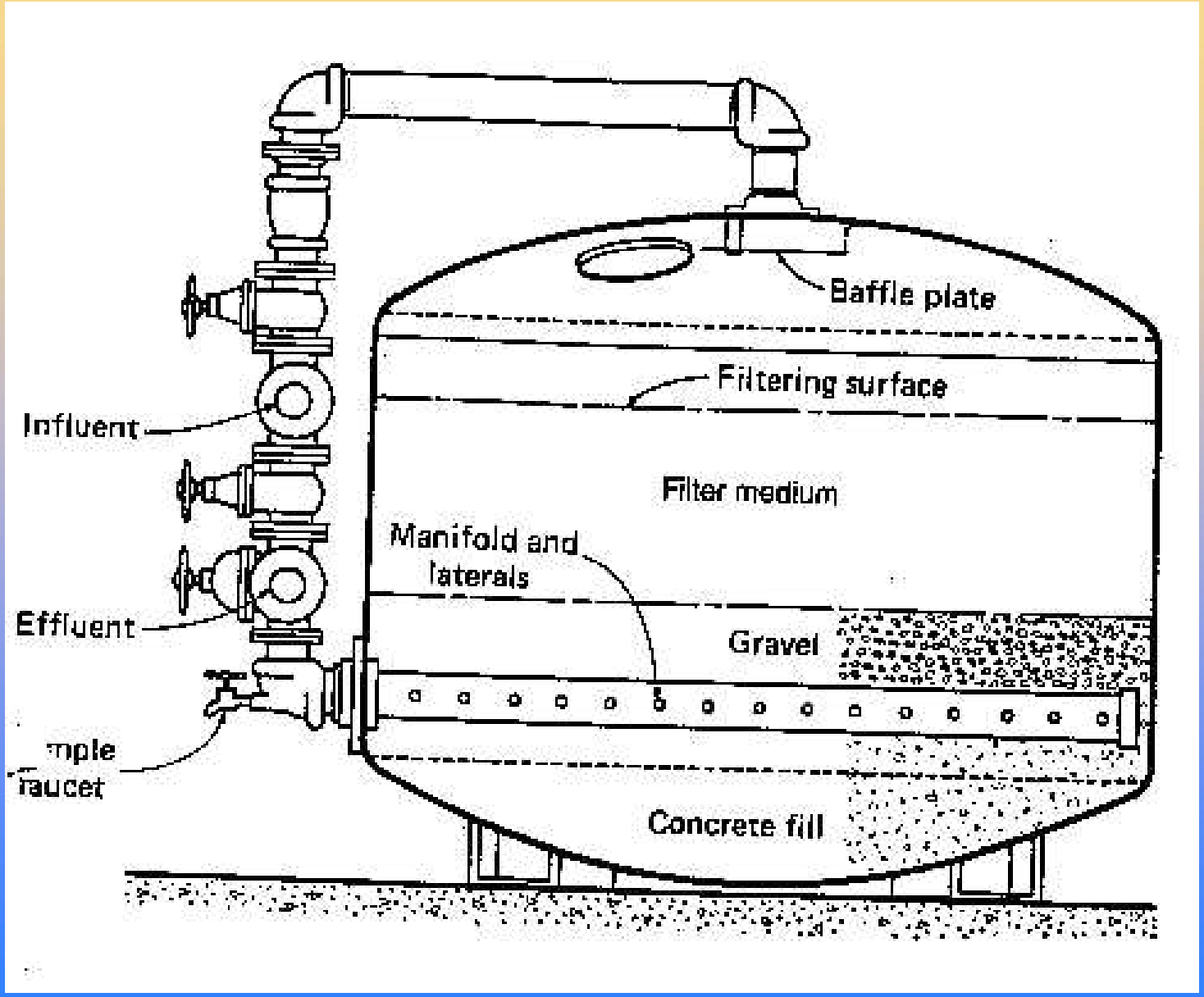


Figure 7.75. Typical schematic of a gravity concrete filter which is in use at the Len waterworks in Zürich (Schalekamp, 1975).

GAC Pressure Filter



GAC Fixed-Bed Adsorbers

Removal of Hazardous Organic Compounds:

Typical Design Parameters

(1) Range of EBCTs in adsorption processes can vary from 5 to 60 minutes for GAC. For removal of synthetic organic compounds (SOCs) from water EBCTs range from 5 to 30 minutes.

(2) Particle Size .8 - 1.3 mm.

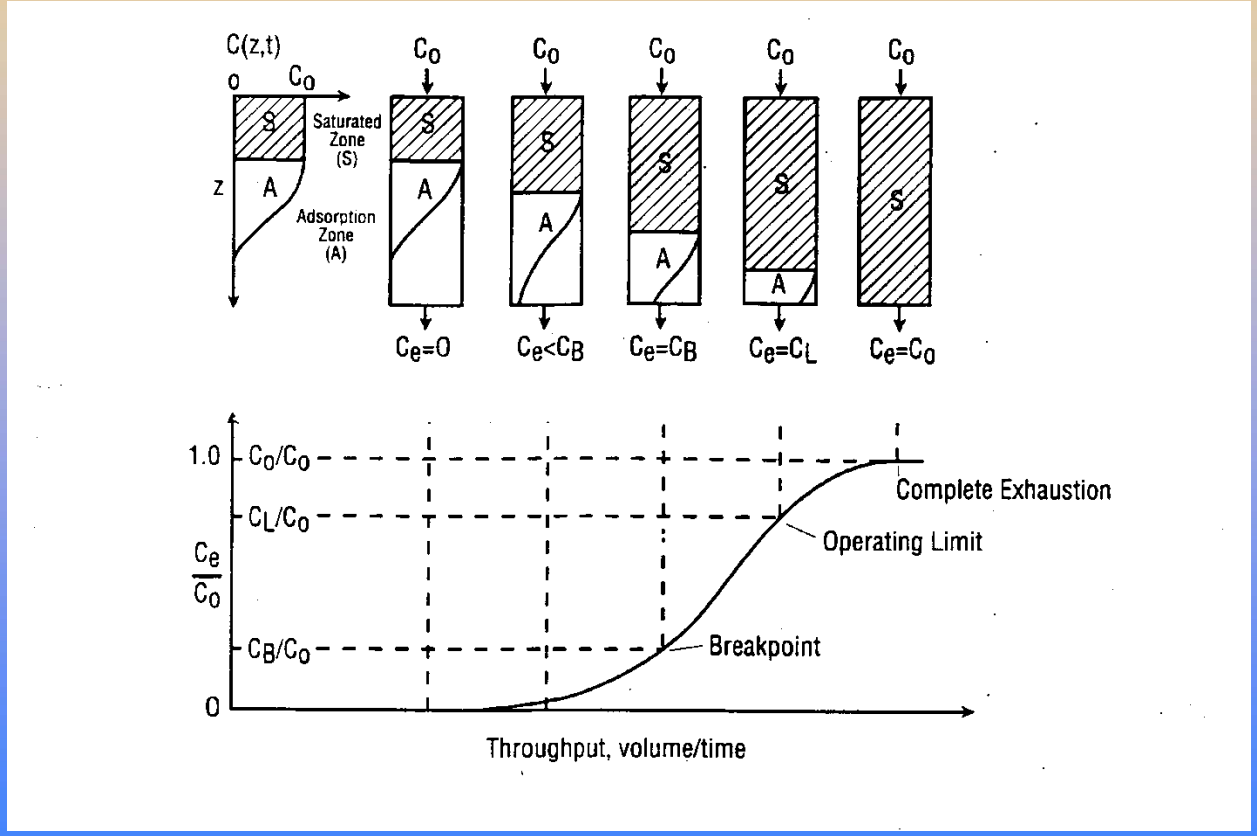
(3) 2 Beds operated in series may reduce amount of GAC needed per liter of water treated by 25 - 50 %. Usually not worth the yard piping unless bed life is less than 3 - 6 months.

(4) Backwashing is to be avoided. Turbidity removal may be required.

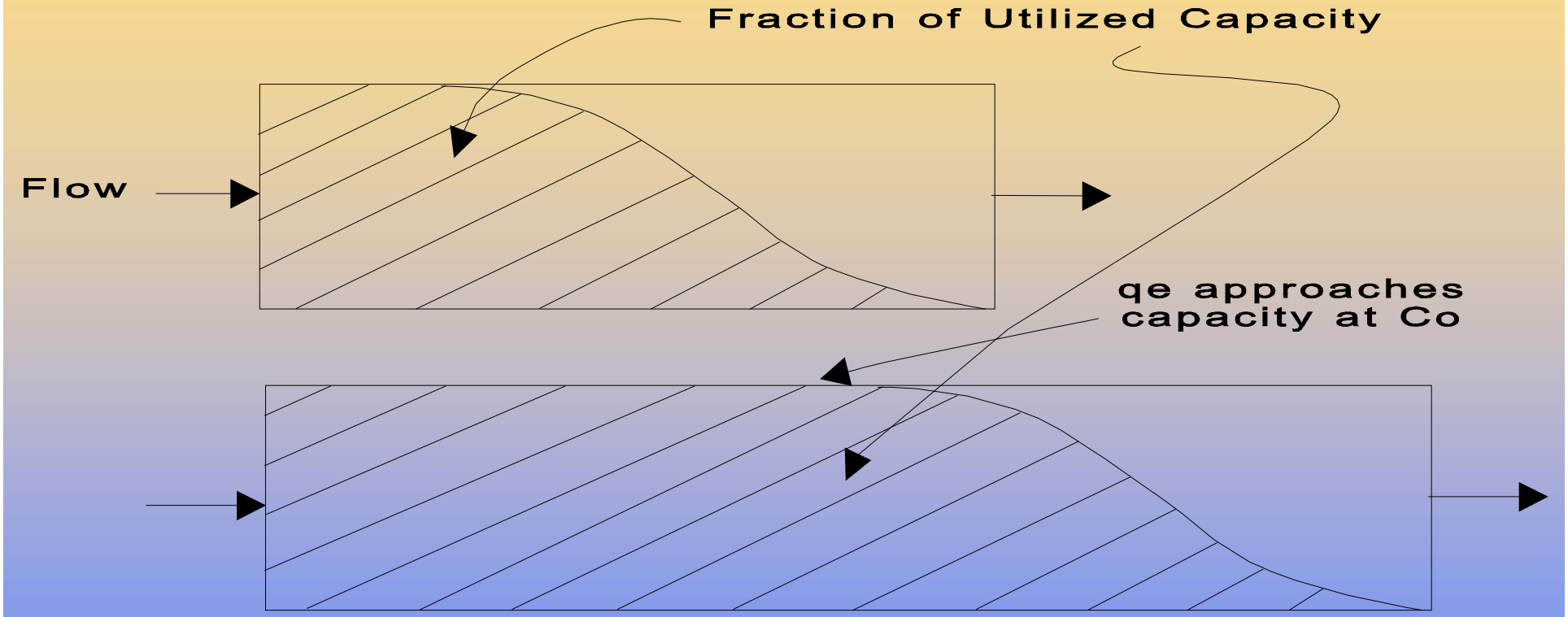
(5) Typical bed density values for GAC are values 350 - 550 kg/m^3 or 22 - 34 lb/ft^3.

(6) Typical filter velocities range from 5 - 15 m/h (2 - 7 gpm/ft^2).

Breakthrough Characteristics of Fixed-Bed GAC Adsorber

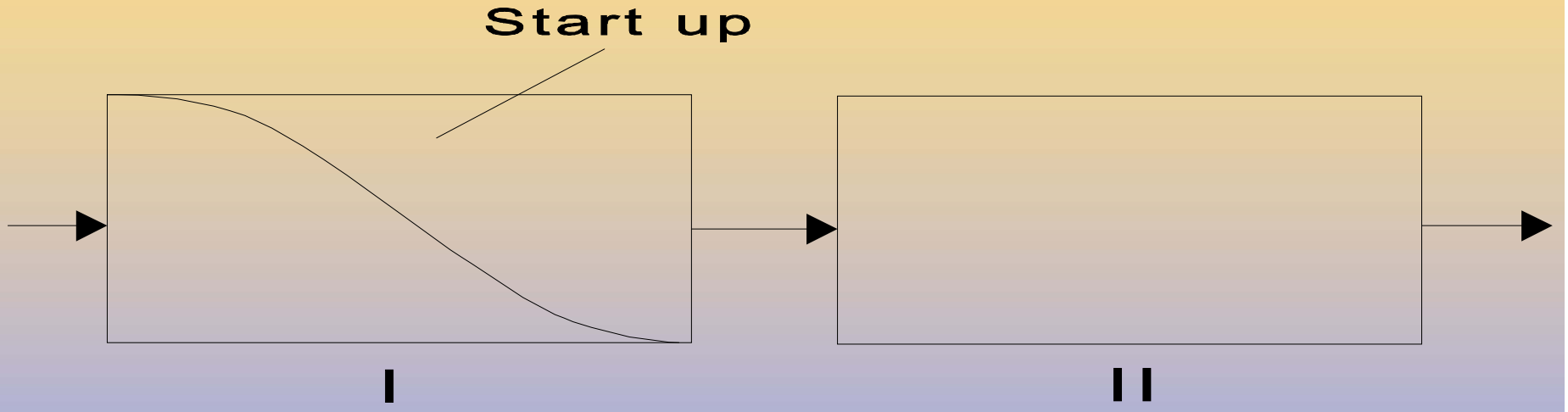


GAC Column Operation



As the length or EBCT increases more capacity is realized.

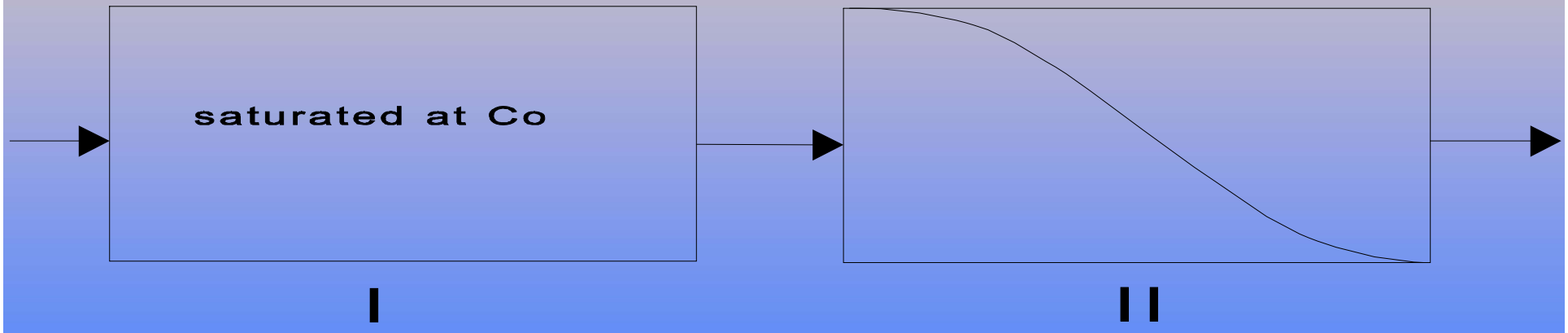
GAC Column Operation



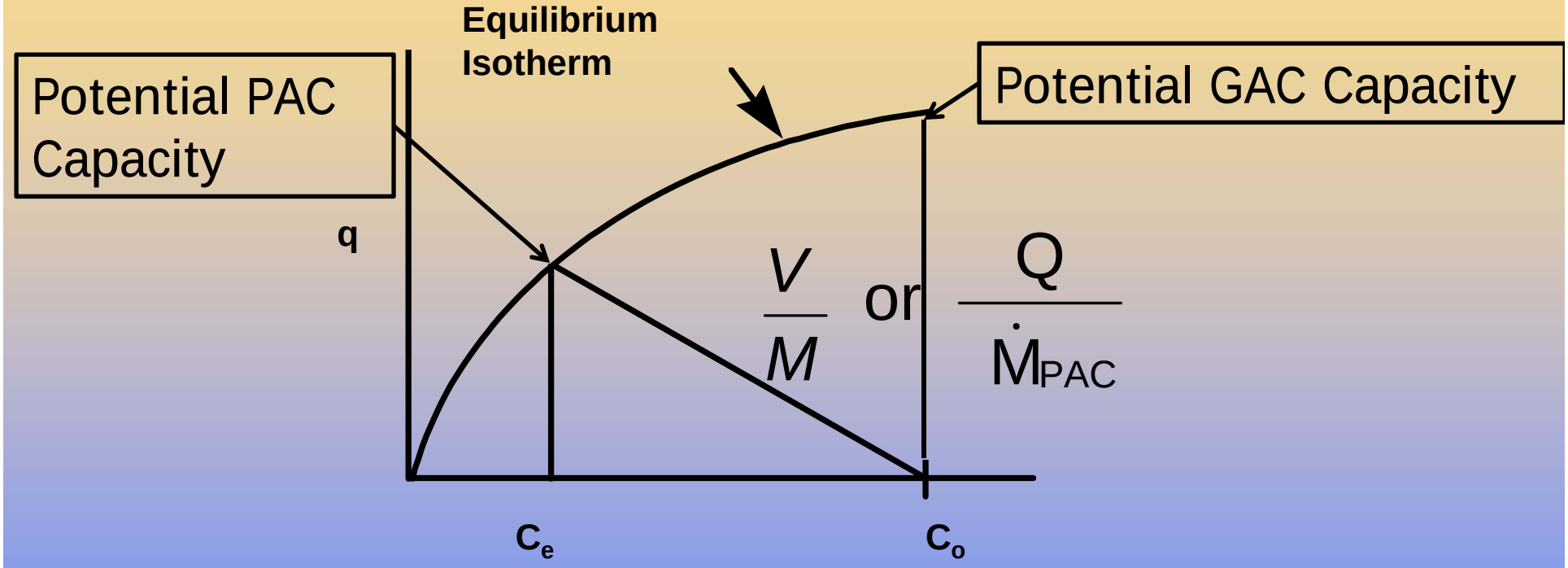
Consider a two beds in-series operation where the length of the MTZ and fixed-beds are the same.

GAC Column Operation

As the MTZ moves from bed I into bed II, bed I is saturated and can be taken off-line and regenerated.



Powdered Activated Carbon (PAC) Operating Line



$$Q\ C_o = q_e\big|_{C_{TO}}\ \dot{M}_{PAC} + Q\ C_{TO}$$

$$\frac{\dot{M}_{PAC}}{Q} = \frac{C_o - C_{TO}}{q_e\big|_{C_{TO}}}$$

Granular Activated Carbon (GAC)
Lowest Carbon Usage Rate

For this case, no solute leaves the bed and we reactivate saturated GAC.

$$t\,Q\,C_o = q_e\big|_{C_O}\,M_{GAC}$$

$$\frac{M_{GAC}}{t\;Q} = \frac{C_o}{q_e\big|_{C_o}}$$

GAC versus PAC
Lowest Carbon Usage Rate

$$\frac{M_{GAC}}{t\ Q} = \frac{C_o}{q_e\big|_{C_o}}$$

$$\frac{\dot{M}_{PAC}}{Q} = \frac{C_o - C_{TO}}{q_e\big|_{C_{TO}}}$$

$$\frac{PAC}{GAC} = \frac{mg/L}{mg/L} = \frac{1 - C_{TO}/C_o}{q_e\big|_{C_{TO}} / q_e\big|_{C_o}} = \frac{1 - C_{TO}/C_o}{\left(\frac{C_{TO}}{C_o}\right)^{1/n}}$$

For a Freundlich Isotherm

$$q = K C^{1/n}$$

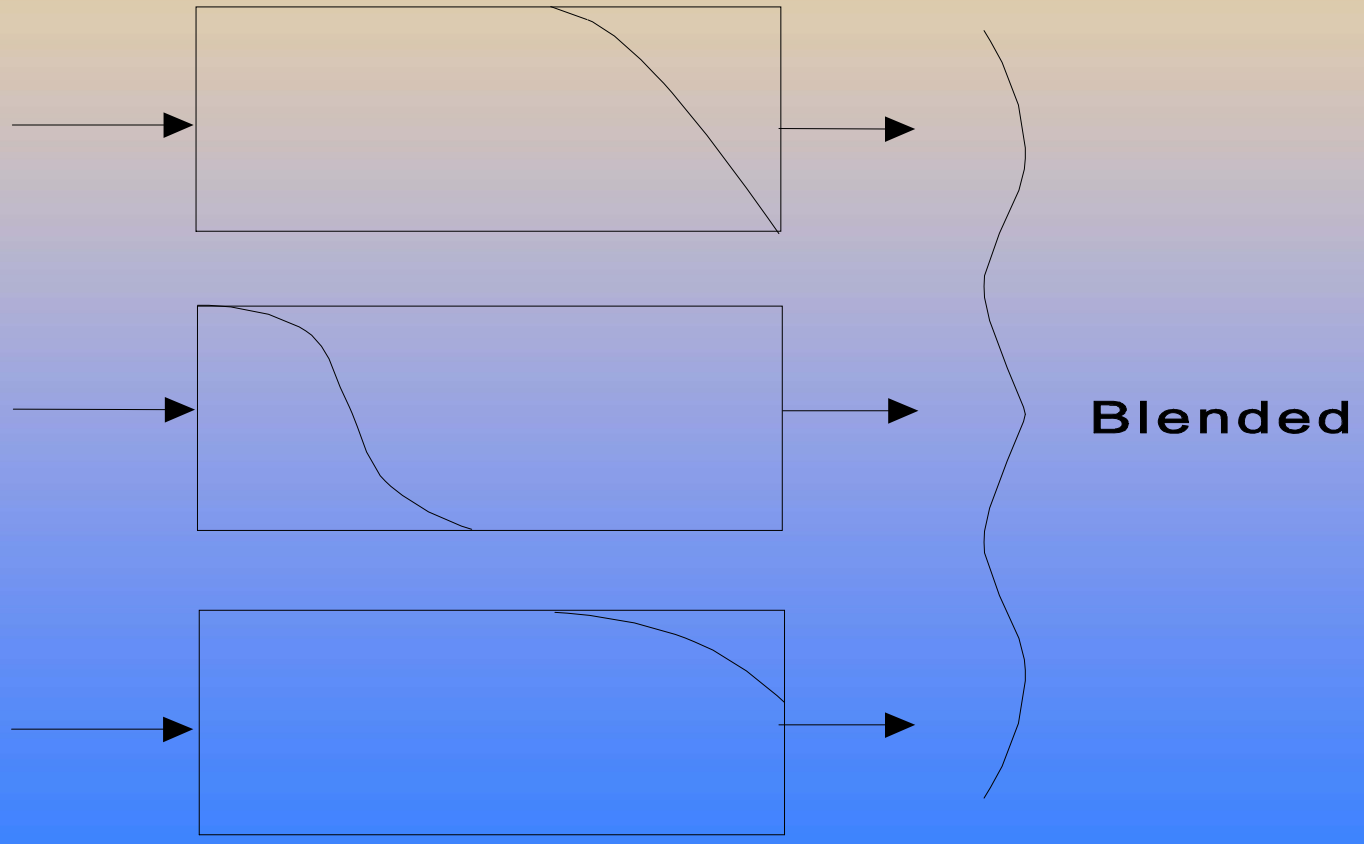
GAC versus PAC Lowest Carbon Usage Rate

PAC/GAC Dosages for various percent removals

1/n	50%	90%	95%	99%
0.2	1.14	1.43	1.73	2.51
0.5	1.41	2.84	4.25	9.9
0.8	1.74	5.70	10.40	39.4

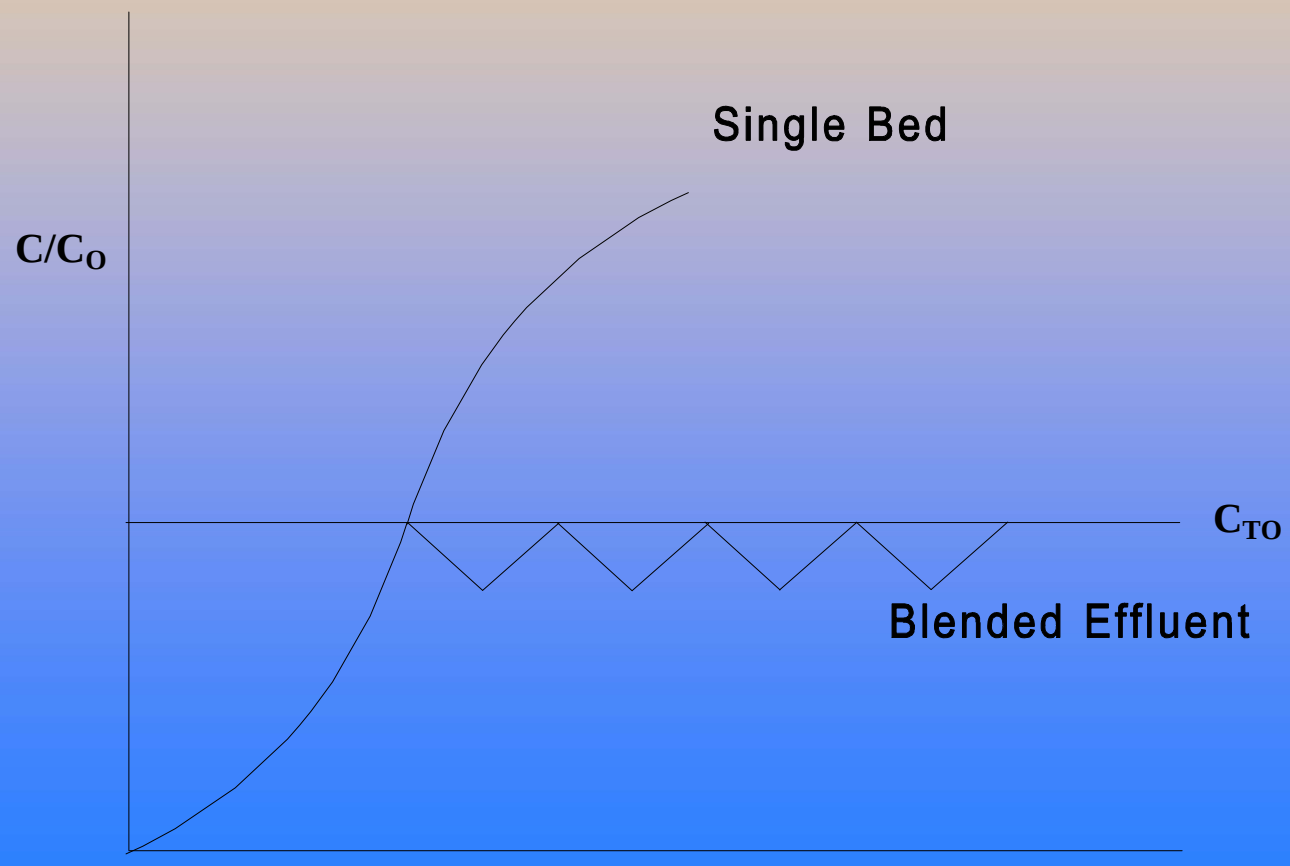
GAC Column Operation

Consider a beds in-parallel operation as shown below:



GAC Column Operation

A beds in-parallel operation will utilize more column capacity than a single bed operation specially for less stringent treatment objectives (e.g. $C/C_{TO} > 0.3$).



Limitations for Adsorption

- **Activated carbon will not remove soluble smaller organic compounds.**
- **Spent adsorbent may be a hazardous waste and has to be reactivated.**
- **Previously adsorbed compounds can desorb and in some cases appear in effluent at concentrations higher than present in the influent.**